


SCIENTIFIC INSTRUMENTS  
FOR LUNAR EXPLORATION

Part B


SURVEYORS, ROVING VEHICLES,  
AND ROUGH-LANDED PROBES

Advanced Studies Document 760-3

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May 1, 1967

## FOREWORD

This document is the second of a series of publications for describing, in considerable detail, the various scientific instruments that can be used for lunar exploration. Part A, EPD-472, discussed those scientific instruments that could be used from an unmanned lunar orbiter. Part B, this document, discusses scientific instruments for Surveyors, Roving Vehicles, and Rough-Landed Probes. Part C discusses scientific instruments for the manned phase of lunar exploration.

## ACKNOWLEDGMENT

The assistance of the following Space Sciences Division engineers and scientists in preparing this document is gratefully acknowledged.

J. A. Dunne  
E. Franzgrote  
C. E. Giffin  
G. M. Hotz  
A. Loomis  
W. S. McDonald  
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## SECTION I

### INTRODUCTION

The scientific objectives, or goals-of-science, of our unmanned lunar program can be synthesized from our present knowledge of the Moon, as derived from the research of several scientific disciplines. Ideally, such goals should be broad in scope, not related to a particular spacecraft or experiment, but rather encompassing disciplines and experiments to relate problems fundamental to an understanding of the nature and origin of the Earth-Moon system, the solar system, and the universe itself. Once these all-inclusive goals of science for the lunar program have been attested and its priorities established, experiments can be devised to satisfy these objectives, and the various experiments, in turn, can be related to particular spacecraft and mission profiles.

The Space Science Board of the National Academy of Sciences (Ref. 1) has defined these goals for lunar research in terms of three categories of basic problems concerning the Moon. These three categories have been further elaborated by defining a number of basic questions that should be answered in a total program of lunar exploration. The Space Science Board Questions encompass virtually all problems of lunar research and should be seriously considered in determining the objectives of lunar exploration. Obviously, however, no one manned or unmanned program can answer all of these basic scientific questions about the Moon. Thus, the total program for lunar research must involve laboratory studies, as well as lunar impacters, orbiters, hard landers, soft landers, and manned missions.

The Office of Advanced Studies at the Jet Propulsion Laboratory has been asked by NASA Headquarters, Office of Lunar and Planetary Programs, to determine the most effective scientific manner in which all of the required objectives for lunar exploration can be accomplished, and to derive a total exploration program in terms of a mix of specific projects and missions. One part of the above task involves the derivation of an extended list of scientific instruments and objectives that may be applied as a solution to the Space Science Board Questions. The purpose of this document is to derive such a list for Surveyors, Roving Vehicles, and Rough-Landed Probes.

## SECTION II

### MISSION DEFINITION

#### A. GENERAL

The geology of the Earth has been synthesized from a prodigious amount of data that was contributed from many observations and scientific disciplines and acquired over a time span of several decades. There is every reason to suppose that knowledge about lunar geology, that is, knowledge of the structure and processes of the lunar interior, of the composition, structure and processes of the lunar surface, and of the history of the Moon, will be unfolded in the same way. True, our working hypotheses have matured through experience and we have the terrestrial sphere as an accessible geological example, but the true picture of lunar geology can only be formed from acquired data. As an example, for the Earth internal forces connected with diastrophism and epeirogenic processes slowly uplift or depress large segments of the crust to form mountains and other constructional land forms, whereas the forces of weathering and erosion operate to sculpture and ultimately destroy the elevated region. Terrestrial surface features are thus seen to be the net effect of internal forces of construction and external forces of weathering and erosion. This information can be applied to the Moon as a working hypothesis; however, its proof will depend on a variety of lunar scientific observations. Even such an apparently simple thing as the composition of the Moon cannot be determined by a few point measurements of elemental composition, but rather will require at the very least a synthesis of data involving many measurements of lunar mineralogy and petrology from samples acquired from a number of areas. Also, this surface compositional data will be the most meaningful when considered in conjunction with data on the internal structure of the Moon, which incidentally will require carrying out select scientific observations, not only at dispersed geographic locations but also over extended time periods.

The point made above is: a few simple missions are not going to unfold the story of lunar geology or answer the questions about the Moon posed by the Space Science Board. Also, it should be apparent that to answer the fundamental questions regarding the cosmogonic significance of the Moon is going to require a

good understanding of lunar geology. All this suggests the importance of an integrated lunar exploration program which will exploit fully the characteristics of a particular mission to acquire pertinent lunar data at minimum cost.

## B. RATIONALE

Unmanned lunar surface vehicles such as Surveyors, Rovers, and Probes can be instrumented to make a significant contribution in a program of lunar exploration. Although the use of these vehicles is not a complete panacea for all the problems apparent in the lunar program, they do present, when used in conjunction with unmanned lunar orbiters, a relatively low cost low-risk high-return technique for lunar exploration.

The mission rationale presented here is to use a soft-landed spacecraft as a basic bus in the task of unmanned lunar surface exploration. This basic bus would accommodate its own complement of scientific instruments or be used to deliver a Lunar Roving Vehicle to the Moon.

At the present stage of our planning for a lunar exploration program the most logical choice for a basic bus is Surveyor. The capability of this vehicle to land and operate on the lunar surface has already been demonstrated. It is a versatile spacecraft that is able to accommodate a broad spectrum of lunar scientific instruments and is adaptive to several different types of missions which may be important in a program of lunar exploration. For example, with proper support from a lunar orbiter communication relay link, Surveyor can be used for a Moon backside mission or a mission out of the so-called Apollo zone which can even include the hard-to-reach lunar polar regions.

The Surveyor spacecraft can be considered to be composed of two major items, viz., the basic bus and the payload. The basic bus furnishes all the subsystems and functions required for transport, maintenance, and off-loading or operation of the payload on the lunar surface, and will not be discussed in detail here. The nominal injected gross weight of the so-called Block I Surveyor spacecraft is about 2200 pounds, which includes a basic bus weight of about 700 pounds, about 1435 pounds of propellants, and 65 pounds of payload. Follow-on Surveyors are expected to have an injected gross weight of up to 2800 pounds which will allow delivery of approximately 200 pounds of scientific payload to the lunar surface.

The scientific instruments for a Surveyor mission are discussed in Section III.

The Lunar Roving Vehicle is here defined as a lightweight, self-contained mobile vehicle that is capable of ranging up to 40 km over the lunar surface. The vehicle weight and size are expected to be compatible with the capabilities of the Surveyor spacecraft and the manned Apollo Lunar Module. As indicated earlier, the total payload capability of the follow-on 2800-pound Surveyor is expected to be about 200 pounds; however, basic support and engineering equipment on the Surveyor bus, such as the Roving Vehicle off-loading mechanism, are expected to reduce the total weight available for the Rover. This suggests that the Surveyor Lunar Roving Vehicle (SLRV) will weigh about 175 pounds and carry perhaps 35 pounds of science payload. The scientific instruments for a Roving Vehicle Mission are discussed in Section IV.

When Surveyors are launched into rough areas on the Moon (as is desirable to supplement manned exploration without adding to its hazards) it may be worthwhile to package the instruments in such a way that they can survive toppling or even destruction of the basic bus upon landing. Such rugged instrumentation would be in the same category as that formerly proposed for the Apollo-based rough-landed Lunar Survey Probe concept. For either delivery mode, the instruments appropriate to the experimental objectives considered here are discussed in Section V.

## SECTION III

## SURVEYOR

## A. GENERAL

In the following pages a number of scientific instruments that can be accommodated on a Surveyor spacecraft are discussed in considerable detail. The instruments are classified into three lists which relate a particular Surveyor mission and its scientific objectives with possible scientific instruments. List I (Table 1) includes those scientific instruments that have been designed for the Block I Surveyor mission. The mission objectives here are as follows:

- (1) Develop lunar soft landing technology and demonstrate basic techniques to be used later for manned landings.
- (2) Survey a number of potential Apollo landing sites to determine their suitability for manned landings.
- (3) Make measurements of lunar-surface characteristics to improve our understanding of the nature of the Moon.

List I, scientific instruments, as discussed in the text, are: (1) approach camera, (2) survey camera, (3) alpha scattering, (4) micrometeorite ejecta (5) single-axis seismometer, (6) touchdown dynamics, (7) soil mechanics, and (8) surface sampler.

List II (Table 2) includes those scientific instruments that will most directly contribute to our knowledge of lunar geology. The mission objectives here largely relate to the Space Science Board Questions regarding the composition, structure, and processes of the lunar surface, although the experiment package could be expected to provide some information regarding the history of the Moon. List II scientific instruments, as discussed in the text, are: (8) surface sampler, (9) drill, (10) processor, (11) X-ray diffractometer, (12) X-ray spectrometer, (13) petrographic microscope, (14) gas chromatograph, (15) subsurface probe, and (16) facsimile camera.

List III (Table 3) includes those scientific instruments that will contribute to our knowledge of lunar geophysics. The mission objectives here largely relate to the Space Science Board Questions regarding the structure and processes of the lunar interior. It should be noted that it is desirable to operate these instruments over an extended period of time, say at least one lunation. List III scientific instruments, as discussed in the text, are: (16) facsimile camera, (17) passive seismic, (18) atmosphere experimenter (19) magnetometer, (20) solar plasma spectrometer (21) electric and magnetic fields, (22) ranging, and (23) dosimeter.

Table 1. Surveyor Science, List I

Instrument/Experiment	Weight in Lbs.	Objectives
1. Approach Camera	12	Provide pictures of the lunar surface during the approach-descent phase of the landing operation.
2. Survey Camera (2 cameras)	16 ea.	Provide high-resolution panoramic photography of the visible lunar terrain in the vicinity of the landed spacecraft. Camera system has colorimetric, polarimetric, and stereometric capability.
3. Alpha Scattering	15	Provide an <u>in situ</u> elemental chemical analysis of the lunar surface near the landed spacecraft.
4. Micrometeorite Ejecta	10	Measure the momentum and velocity of micro-sized dust particles near the lunar surface.
5. Single-Axis Seismometer	10	Provide information on lunar seismic activity, background noise level, distribution of meteor impacts, elastic properties, and the internal constitution and structure of the Moon.
6. Touchdown Dynamics	25	Provide a history of the linear and angular motion of the spacecraft during the touchdown phase.
7. Soil Mechanics	10	Examine the nature and mechanical properties of lunar surface material under the landed spacecraft.
8. Surface Sampler	14	Examine the nature and mechanical properties of lunar surface material around the landed spacecraft.

Table 2. Surveyor Science, List II

Instrument/Experiment	Weight in Lbs.	Objectives
8. Surface Sampler	14	Examine the nature and mechanical properties of lunar surface material around the landed spacecraft, and acquire samples for the fixed-analysis instruments.
9. Lunar Drill/Sampler	15	Sample acquisition, prepare hole for subsurface instruments, and examine the physical properties and stratification of lunar surface material as a function of depth.
10. Sampler Processor/Transporter	5	Prepare samples from surface sampler and drill for the fixed-analysis instruments.
11. X-ray Diffractometer	15	Identify the types and relative abundance of crystalline phases present in lunar samples.
12. X-ray Spectrometer	15	Provide information on the elemental composition of lunar material.
13. Petrographic Microscope	15	Identify lunar rock types and determine their genesis; detection, and composition of glass; examine particulate material texture, etc.
14. Gas Chromatograph	10	Identify some of the volatile constituents in lunar surface material.
15. Subsurface Probe	6	Provide information on the density, magnetic susceptibility, and lunar heat flux in a prepared hole.
16. Facsimile Camera	10	Provide high resolution stereo panoramic pictures of the landing site.

Table 3. Surveyor Science, List III

Instrument/Experiment	Weight in Lbs.	Objectives
16. Facsimile Camera	10	Provide high resolution stereo panoramic pictures of the landing site.
17. Passive Seismic	30	Provide information on lunar seismicity, internal structure, thermal properties, etc.
18. Lunar Atmosphere Experiment	17	Provide information on the composition and pressure of the lunar atmosphere.
19. Magnetometer	10	Measure the magnitude, direction and time variations of any lunar magnetic field, to study the interaction between the solar wind and the Moon, etc.
20. Solar-Plasma Spectrometer	15	Measure the low-energy charged particle environment of the lunar surface to aid in understanding the magnetometer data regarding the interaction between the solar wind and the Moon.
21. AC Electric and Magnetic Fields	8	Measure the magnetic and electric field fluctuations at the lunar surface with both a search coil sensor and an electric field sensor.
22. Ranging	10	Determine the selenographic location of a lunar landing site from terrestrial ranging to an accuracy from 1 to 5 meters.
23. Dosimeter	1	Provide data on the biological hazards from energetic radiations resulting from extended lunar surface missions.

## B. SCIENTIFIC INSTRUMENTS

### 1. Approach Camera

This television system was originally designed for the Surveyor spacecraft to provide pictures of the lunar surface during the approach-descent phase of the landing operation. In the suggested mission profile it is operated from about 1000 miles above the lunar surface, or shortly after the start of the spacecraft terminal maneuver, down to about 80 miles above the surface, or immediately prior to main retro ignition. This time interval is sufficient for the exposure and transmission of some 50 pictures. (See Figure 1.)

The specific objectives of the approach-descent pictures for a Surveyor mission are as follows:

- (a) Identify the landing point in lunar coordinates, and correlate this data with existing information, maps, and photographs of the moon;
- (b) Relate, insofar as possible, the landing point to known positional features observed in the approach-descent photographs;
- (c) Provide a general concept of the topography and geology in the vicinity of the landing site;
- (d) Relate the differential photometric information from the approach-descent photographs with present and future terrestrially obtained information;
- (e) Provide information on the relation between photometric measurements, object size, and range;
- (f) Reveal details and extend measurements of lunar surface relief and photometry by taking pictures as close to the lunar surface as the spacecraft landing sequence permits;
- (g) Aid in optimizing the sequence and interpretation of the survey pictures.

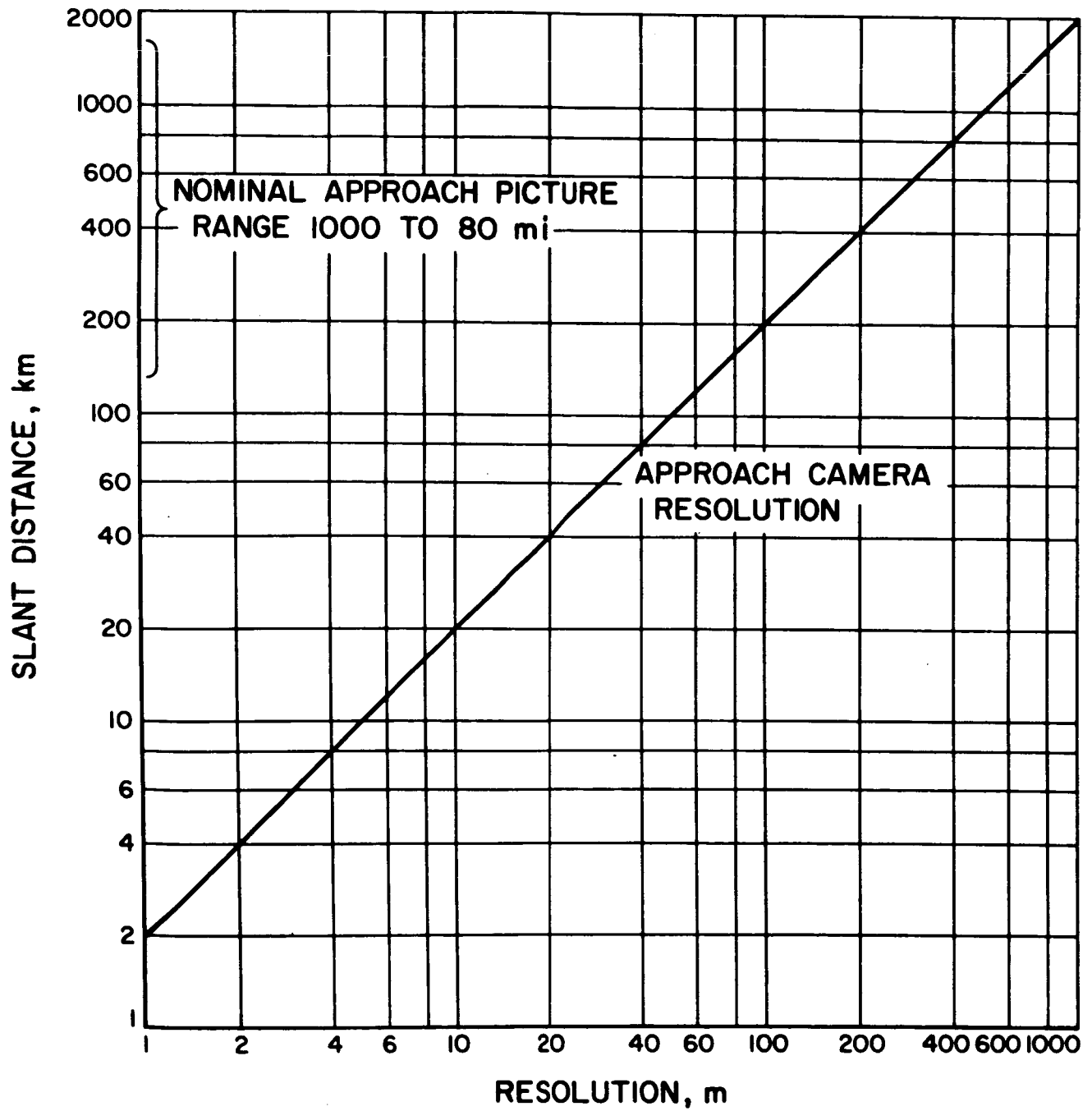


Figure 1. Approach Camera Resolution

The initial field of view of the camera system from an altitude of 1000 miles above the lunar surface is approximately 112 miles on each side with a surface resolution capability of about 2620 feet. The pictures are all overlapped such that at least 50 percent of the lunar surface area portrayed in each picture appears in the preceding picture. The final field of view of the lunar surface taken from an altitude of no greater than 80 miles is approximately 9.3 miles on a side with a surface resolution capability of about 210 feet. If pictures can be taken during the retro and post-retro phases of the descent, then the areal coverage and resolution will change proportionally.

The television camera uses a vidicon sensor and a 100-mm focal-length lens. The square field of view is 6.4 deg on a side. The system is capable of distinguishing at least eight  $\sqrt{2}$  gray levels at a highlight luminance of 800 ft-lamberts. An iris adjustment prior to launch can be used to set the camera at the optimum sensitivity for a lunar-scene luminance from 50 to 2600 ft-lamberts. The complete system including electronics weighs 12 pounds.

Approach cameras are not planned for the early Surveyor missions.

## 2. Survey Camera

The survey cameras are designed to provide panoramic photography of the lunar terrain visible in the immediate vicinity of the spacecraft, up to and including the horizon. They are capable of a maximum optical resolution better than 1 mm next to the spacecraft and are calibrated for photometric, colorimetric, and polarimetric measurements.

The survey photographs should discriminate between the observable lunar surface units and permit geologic classification and correlation of the units on the basis of their visible properties and also their behavior where the surface is disturbed by the landing gear and the surface sampler. The specific objectives of the system are as follows:

- (a) Provide, as the primary objective, panoramic photographic information of the lunar terrain visible in the immediate vicinity of the spacecraft, up to and including the local horizon;

- (b) Provide measurements of feature size, shape, and range, through photogrammetry;
- (c) Provide photometric, colorimetric, and polarimetric measurements of selected regions of the visible lunar surface, to aid in differentiating the observed features;
- (d) Produce topographic or form-line maps of the observable vicinity of the spacecraft, for use in geologic interpretation of the observed features;
- (e) Accurately locate the spacecraft landing position on the Moon by stellar position measurements;
- (f) Observe lunar surface features at different angles of solar illumination to assist in differentiating and correlating the visual information, in identifying the lunar surface features, and in enhancing the accuracy of the topographic measurements;
- (g) Observe phenomena taking place on the surface of the Moon, such as the formation of new craters by micrometeoroids and secondary solid particles, by successive observations of regions of the lunar terrain and coordination with the results of other payload experiments; and,
- (h) Monitor the operation of other scientific instruments.

Each survey camera is equipped with a variable focal length lens (25 to 100 mm) that can be commanded to provide a 6.4 x 6.4 deg minimum or a 25.6 x 25.6 deg maximum field of view. In both wide- and narrow-angle modes, the system is capable of 360-deg observation in azimuth and 20 deg above and 45 deg below the horizontal plane of the spacecraft. An automatic iris is provided (f/4 to f/22). Provision is also made for the insertion of colored or polarized filters into the optical path on command from Earth. Less than one-third of the area visible to two survey cameras can be viewed stereoscopically because of spacecraft obstructions and baseline requirements. Each camera weighs approximately 16 pounds, including the electronics. One survey camera was carried by Surveyor I and successfully demonstrated all of the above functions except those dependent upon stereo viewing from two cameras.

### 3. Alpha Scattering

The alpha-scattering experiment is designed to provide an in situ chemical analysis of the lunar surface material. After landing of the Surveyor spacecraft, the instrument sensor is deployed directly to the lunar surface by an extension mechanism; it can be repositioned by the surface sampler. In operation, a sample is bombarded by 6 million electron-volt (Mev) alpha particles from Curium 242. The energy spectrum of alpha particles scattered from the sample, at a given angle, is characteristic of the mass of the scattering nucleus. The scattered alpha particles are detected with a solid-state detector, and the energy of each particle is obtained by pulse-height analysis of the output of the detector. The energy spectrum of protons emitted in alpha-proton ( $\alpha$ , p) nuclear reactions, when certain of the lighter elements are bombarded by alpha particles, is obtained by a separate detector-analyzer system.

The alpha-scattering detector-analyzer system should detect scattered alpha particles from all elements of atomic number five (boron) and greater, and it should resolve mass numbers differing by one unit in the range from atomic number five (boron) to atomic number fourteen (silicon). (See Table 4.)

The proton detector-analyzer system has the capability to detect protons from the following elements: lithium, boron, nitrogen, fluorine, sodium, magnesium, aluminum, silicon, phosphorus and sulfur.

The basic theory of the alpha scattering technique has been presented by Patterson, et al (Ref. 2). Trombka has developed a method for analyzing complex chemical mixtures by a best-fit least-square computer technique (Ref. 3).

The instrument weighs about 8 pounds including sensor and electronics. The deployment mechanism and auxiliary electronics weighs an additional 7 pounds.

Table 4. Range of the Instrument

Atomic Number	Element		Detection Limit %
3	Li	Lithium	?
4	Be	Beryllium	?
5	B	Boron	1
6	C	Carbon	0.1
7	N	Nitrogen	1
8	O	Oxygen	1
9	F	Fluorine	1
11	Na	Sodium	1
12	Mg	Magnesium	1
13	Al	Aluminum	1
14	Si	Silicon	1
15	P	Phosphorus	1
16	S	Sulfur	1
17	Cl	Chlorine	1
> 17	All elements greater than chlorine in atomic number		

The detection limits will vary with the individual elements. Elements of atomic number 15 (phosphorus) and higher will probably not be resolved as single elements but as groups (e. g., Mn, Fe, Ni).

#### 4. Micrometeorite Ejecta

The micrometeorite instrument is designed to measure the momentum and velocity of micro-sized dust particles near the lunar surface. The specific objectives are as follows.

- (a) Measure the number, mass, speed, and trajectory of individual micrometeorite and ejecta particles at the lunar surface;
- (b) Recognize and study ejecta from a single micrometeorite impact event by measurements of the time and trajectory relationships of individual ejecta particles;
- (c) Discriminate between primary micrometeorite particles impacting the lunar surface and the ejecta particles thrown out by the impact;
- (d) Evaluate the influx rate of interplanetary material on the lunar surface;
- (e) Evaluate the enhancement of the primary influx rate by the ejecta phenomenon at the lunar surface;
- (f) Assist in the study of the nature of the lunar surface, as determined by the interaction between the surface and the impacting particles;
- (g) Assist in the study of the evolutionary processes of the Moon;
- (h) Investigate the contribution of lunar ejecta material to the dust particle distributions in interplanetary, cis-lunar, and near-Earth space;
- (i) Evaluate the hazards confronting manned and unmanned explorations of the lunar surface.

The instrument is made up of three basic sensors: an impact plate with an effective area of  $1000 \text{ cm}^2$  and two thin-film capacitors. An acoustic transducer bonded to one side of the impact plate detects signals related to the momentum of the striking particle. The capacitors consist of a thin film of dielectric bonded to each side of the impact plate and covered with a layer of conducting

material. Penetration of either capacitor produces a pulse which is related to the particle energy. Pulse height analysis of both the acoustic signal (momentum) and the capacitor signal (energy) enables the number, mass and speed of particles to be determined. The acoustic transducer is sensitive to particles with momentum greater than  $10^{-5}$  dyne-sec, while the capacitor films have been shown to be sensitive to energies greater than that of a  $10^{-13}$  gm particle with a speed of about 1 km/sec ( $10^{-3}$  ergs).

The instrument weighs 10 pounds, including sensors, electronics and mounts.

#### 5. Single-Axis Seismometer

The single-axis seismometer experiment is intended to provide the following information:

- (a) Lunar seismic activity — number, magnitude, and spatial distribution of natural moonquakes;
- (b) Background noise level — spectrum of seismic background noise, correlated, if possible, with thermal, meteorite impact, and other sources, including those generated by the spacecraft;
- (c) Elastic properties:
  - (1) Near surface—from body waves and short-period surface waves;
  - (2) At depth—from body waves and intermediate-period surface waves;
- (d) Internal constitution and structure;
- (e) Distribution of meteorite impacts, their number, and energy.

The instrument consists of a coil-magnet velocity transducer, which is surrounded by an insulating blanket and hard-mounted to the spacecraft. The instrument has a natural period of 1 cps and is sensitive in the range from 0.05 to 20 cps. The minimum surface displacement which it can detect is approximately 1/10 millimicron. Spacecraft resonance partially blocks response in the

10 to 20 cps passband. The instrument is provided with a means of self calibration. The complete assembly weighs 10 pounds.

6. Touchdown Dynamics

The touchdown dynamics experiment is intended to provide a history of the linear and angular motion of the Surveyor spacecraft during the touchdown phase of the mission profile. The specific objectives of this experiment are to:

- (a) Determine linear and angular acceleration, velocity, and displacement of the spacecraft reference axes during touchdown, and express these motions in a lunar inertial reference system;
- (b) Obtain information on bearing strength of the lunar surface;
- (c) Obtain information on shearing resistance or coefficient of friction of lunar surface for both static and dynamic conditions;
- (d) Obtain information on the penetration of the spacecraft into the lunar surface; and,
- (e) Obtain information on lunar surface contour in the landing area.

The touchdown dynamics experiment consists of a tape recorder and 24 sensors to measure the following parameters:

- (a) Three orthogonal components of linear acceleration and roll rates of the main spaceframe structure;
- (b) Magnitude of loads in the landing leg structures from which force vectors on each foot pad are computed;
- (c) Position of each landing leg relative to the spaceframe;
- (d) Time of surface contact for each foot pad and crushable block.

Preliminary data, such as linear accelerations in body axes, roll rates, leg-structure relative locations, and forces in leg structures, are expected to be accurate to the minimum resolution element of  $\pm 2$  percent.

The initial velocity of the spacecraft at touchdown will be calculated using doppler radar and rate gyro data during the free-fall period after vernier engine shutoff. Linear accelerations, velocity, and displacements determined by the accelerometers will be combined with the rate gyro data to track the spacecraft center of gravity during and after the impact.

The strain gages and position potentiometers on the landing gear will measure the bearing strength and shearing resistance of the surface when combined with the motion of the center of gravity.

Information on the penetration of the footpads and crushable blocks into the surface will be derived from an analysis of the load components parallel and normal to the direction of the resultant velocity vectors. Total weight of the experiment is about 25 pounds.

#### 7. Soil Mechanics

The soil mechanics experiment is designed to determine the nature and mechanical properties of the lunar surface using various instrumentation to measure properties which are critical in the design of lunar surface structures, shelters, and moving vehicles and to assist in the design of mechanisms employed in landing future spacecraft on the lunar surface. The specific objectives of the soil mechanics experiment are as follows:

- (a) Identify the lunar surface model in terms of materials and configuration;
- (b) Determine the mechanical properties of the lunar surface material;
- (c) Identify the mechanical properties of each layer of surface material, if the model consists of more than one layer within the depth of investigation of the instrumentation.

A variety of instrument techniques have been suggested to measure some of the soil properties that are of interest in this experiment. These have varied from techniques in which the load bearing capacity of a soil is measured as a function of penetration of axially loaded flat plates, or pointed penetrometers.

From such data, under controlled conditions, it is possible to derive the cohesive modulus, frictional modulus, and bearing capacity of tested soils. By relating the shear torque as a function of axial load and angular displacement in an appropriate instrument, it is even possible to derive the cohesion coefficient and the friction angle of the tested soil.

It is desirable to monitor the operation of this experiment with the TV system and to observe the lunar soil prior to instrument deployment. Instrument weight is about 10 pounds.

#### 8. Surface Sampler

The surface sampler is instrumented with strain gages, position potentiometers, and a dual-range accelerometer which measures deceleration in the 0-50 g and 0-2000 g ranges. The scoop can be manipulated through an azimuth motion of 150 deg and over an extension of 5 feet, and it is retracted from the extended position by a drag line which can exert a pull of 20 pounds. The instrument can be used to retrieve objects on the surface, to determine the nature and mechanical properties of the lunar surface material by trenching or chipping, and to move the alpha-scattering instrument to a new surface position. Note that a tool steel blade on the scoop can be used as a pick, and that it is capable of cracking a one-inch thick concrete slab. Also, the sampler is capable of providing detailed topographic measurements over the 30 square foot area within its reach with an accuracy of  $\pm 0.3$  inch.

Estimates of surface bearing strength under static loading conditions may be obtained throughout this area by monitoring the penetration of the scoop during the application of two static force ranges, 1.5 pounds per square inch (door closed) and 75 psi (door open).

Measurements of displacement, horizontal force, and vertical load during shear tests with the sampler will confirm and extend the static bearing strength data. If the lunar surface is impenetrable, some estimate of frictional behavior will be obtained. If the material is penetrable, trenching can be carried out to a maximum depth of 20 inches, permitting bearing capacity tests at successively lower depths.

Four basic modes of dynamic operation, in addition to variation of drop height and sampler extension, provide a very large range for measurement of the dynamic behavior of the surface. Deceleration-versus-time histories and impact velocity measurements will classify the lunar surface material as granular, porous, or solid and will determine the quantitative mechanical properties in terms of the modulus of elasticity and yield strength.

The instrument weighs about 14 pounds.

The soil mechanics-surface sampler experiment to be flown on the early Surveyors is a simplified version of the experiment described above. This is the same mechanism but is only partly instrumented for force and motion measurements.

#### 9. Lunar Drill/Sampler

A drill on a Surveyor follow-on spacecraft would have the following objectives:

- (a) Sample acquisition — obtain subsurface lunar soil samples for analysis by spacecraft instruments;
- (b) Prepare hole for insertion of subsurface instruments;
- (c) Analytic tool — determine the hardness properties and stratification of lunar surface material as a function of depth.

Surveyor I photographs show the lunar surface at the landing point to be granular to a depth of several inches. Craters photographed in the same area suggest that the subsurface is granular (soil-like) to a depth of at least several meters. Although rocks and boulders are also present in this area, it appears that the probability of randomly landing over a sizable one is not great. Accordingly, assuming that this represents a typical landing site for Surveyor follow-on spacecraft, the inclusion of a rotary impact hard rock drill is not recommended, but a simpler rotary drill sampler is proposed.

Such a device is the combined rotary drill, helical conveyor, sampler with a thin casing which remains in the hole to prevent cave in. It would drill a 1-1/4 inch hole about 3 feet deep unless it encountered a hard rock which it could

not push aside. In such case both drill and casing would retract and try an alternate spot several inches from the first. The drill system consists of a helical conveyor with an integral drill tip rotated by a motor at approximately 300 rpm. This system, together with a non-rotating casing, is deployed vertically by a motor-driven lead screw actuated by a force sensor. As the drill descends, the displaced soil (if less than approximately 2 mm in size) may be transported up the helical conveyor or (if larger) pushed aside. Consolidated material is fragmented into small particles which can be carried up the conveyor to the sampler receiver. When the drill reaches full depth, it is retracted, leaving the casing in the hole. Next, the subsurface probe is indexed into place and is lowered into the cased hole. Estimated weight is 15 pounds; estimated max. power is 100 watts; and, total energy is 75 watt-hrs.

#### 10. Sampler Processor/Transport

Lunar subsurface material acquired by the lunar drill-sampler is delivered first into the sampler receiver (hopper). As this receiver may alternately be used to accept samples from the surface sampler, a coarse screen is employed at the receiver entrance to discard any particulate larger than approximately 4 mm. Below this coarse screen another screen, with approximately 700 $\mu$  opening, is employed to divert particles from 4 mm to 700 $\mu$  (or 2 mm to 700 $\mu$  if from the drill-sampler) in size to a crusher receptacle. These pebbles are next fed into a low-powered (approximately 5-10 watt) miniature gyratory crusher which passes a maximum particle size of 300 $\mu$  but supplies enough fine particles to yield a freshly crushed sample suitable for any of the instruments in question: the X-ray diffractometer, the X-ray spectrometer, the gas chromatograph, and the petrographic microscope (which has its own sample separator and processor). Alternately, on command, samples of the naturally comminuted 0 - 700 $\mu$  material in the main sample receiver are suitable for any of the analytical instruments named and may be supplied to them. Thus, the sample processor/transporter system can supply samples from either of two sources--surface samples from the surface sampler or subsurface samples from the drill. Samples from either of these sources are next separated into two basically different types of samples: (1) freshly crushed particulate and (2) naturally occurring fine particulate which was produced by naturally occurring lunar surface comminution processes.

The estimated weight of the processor/transporter system is 5 pounds; the maximum power is 25 watts, and the total energy, 20-watt-hr. Samples would be measured volumetrically and would be transported by screw conveyors.

#### 11. X-Ray Diffractometer

The X-ray diffractometer has been designed to conduct mineralogical analysis of lunar material. The primary objective is to identify the types and the relative abundance of crystalline phases present in a lunar sample. The instrument can provide diffraction data of sufficient quality to assure the identification of any of the major rock-forming and accessory minerals when they exist in quantities of 5 percent or greater by volume in the sample.

The diffractometer system contains two major parts. First, the goniometer subsystem which includes the X-ray tube, gas proportional detector, and sample-handling device, and second, the power supplies and data handling mechanisms. The current design of the instrument represents a miniaturized version of the standard laboratory counter diffractometer except that it is inverted. X-rays from a small, 25 kv X-ray tube with a copper target are incident on the base of a specimen cup with a basal window of 0.002-inch thick beryllium. The diffracted X-rays will exit through the cup base and will be counted by a gas proportional detector. The potential  $2\theta$  range is 10 to 80 degrees and scan rates may be from  $1/2^\circ$  to  $4^\circ/\text{mm}$ . The X-ray optical design provides resolution nearly equivalent to that in laboratory models.

The total weight of the instrument including the head and high-voltage power supply is about 15 pounds. This is one of the fixed-analysis experiments; therefore, it is operated in conjunction with the surface sampler, lunar drill, and the sample processor/distributor. If a radioisotope-thermal generator (RTG) power supply system were used on the Surveyor spacecraft, this instrument would have to be shielded.

Some of the components of this experiment can be shared with the X-ray spectrometer to give a combination instrument weighing about 20 pounds (Ref. 4).

12. X-Ray Spectrometer

The scientific objectives of the experiment (Ref. 5) are to provide information on the elemental composition of materials taken from the lunar surface and subsurface. Towards this objective the instrument will be capable of detecting elements with the following limits of sensitivity (by weight):

<u>Element</u>	<u>Limits of Sensitivity</u> <u>%</u>
Sodium	0.5
Magnesium	0.2
Aluminum	0.1
Silicon	0.1
Sulfur	0.1
Chlorine	0.1
Potassium	0.05
Calcium	0.05
Titanium	0.05
Chromium	0.02
Manganese	0.02
Iron	0.02
Nickel	0.02

The technique involved for this instrument derives from the fact that any material when bombarded by high-energy electrons will emit X-rays of wavelengths which are characteristic of the elements contained in the sample. In the Surveyor X-ray spectrometer electrons (15-25 kv) produced by a self-biased electron gun strike the target at the bottom of the instrument, producing characteristic X-rays and an X-ray continuum. These X-rays are emitted upward into the spectrometer in all directions. Each elemental channel consists of a collimating stack of parallel foils and a diffracting crystal. For a parallel beam incident on each crystal only those X-rays which satisfy the Bragg equation for a given wavelength or higher integral order of  $n$  will be diffracted through the collimating stack. By fixing the value of  $\theta$  through geometrical orientation, it is possible to define the one wavelength which will be diffracted. Eleven geiger

counters and four proportional counters are employed to detect the number of X-rays diffracted into the different channels corresponding to each of the elements of interest.

The instrument consists of an X-ray sensing head, an electronic control and registration system, a standard sample, and a power supply. The X-ray head comprises an excitation source, fixed dispersive and nondispersive analytical channels, and detector circuitry. For lunar operation, a soil transport system positions a prepared sample of lunar rock beneath the viewing port of the spectrometer. The sample specimen is then bombarded by an electron beam as a target in an X-ray tube is bombarded. The X-ray emission of the sample is then counted to determine the elemental composition of material present in the sample. The 15 dispersive channels provided consist of 13 dispersive channels for individual elements and 2 dispersive channels for background levels and calibration. A redundant nondispersive system is provided for identifying radiations from all elements. This channel is very sensitive, but has relatively poor energy resolution and serves mainly to check the data obtained from the dispersive channels.

The total weight of the instrument including the head, electronics, and high-voltage power supply is about 15 pounds. This is one of the fixed analysis experiments. Therefore, it is operated in conjunction with the surface sampler, lunar drill, and the sample processor/distributor. If a radioisotope-thermal-generator (RTG) power supply system were used on the Surveyor spacecraft, this instrument would have to be shielded.

Weight and complexity could be reduced in this experiment by utilizing only nondispersive X-ray spectroscopy techniques, which do not require dispersing crystals and defining slits; however, sensitivity and accuracy are considerably reduced. A further weight, as well as power reduction, could be achieved by using a radioactive excitation source. All in all, the experiment could be reduced in weight to about 7 pounds, but as stated before, the penalty is a severe loss in detection sensitivity and discrimination accuracy.

### 13. Petrographic Microscope

The petrographic microscope (Ref. 6) is designed for remote observation of crushed rock samples in transmitted light. The objectives are:

- (a) Identification of lunar rock type and genesis thereof, by:
  - (1) identification of rock texture;
  - (2) identification of shapes and relative sizes of different mineral grains; and,
  - (3) determination of relative abundances of minerals in sample;
- (b) Detection of glass and estimate of composition of glass by refractive index;
- (c) Determination of particle size and shape distribution of particulate surficial material;
- (d) Identification of phases present in small amounts.

The petrographic microscope system was conceived as an experiment of low weight and power which could provide textural information on rocks and particulate material from the lunar surface. The type of data provided by this system would preclude ambiguities in the interpretation of other petrological experiments. The objectives listed above are of considerable importance in the scientific exploration of the Moon. Except for determinations of bulk mineralogy, this data will not be forthcoming from other instruments.

In operation, a sample of lunar material consisting of sized particles in the range of 10 to 300 $\mu$  is delivered to the microscope from the spacecraft sample processor/distributor system. The microscope system separates these particles into fine-grained and coarse-grained fractions. Each fraction is then immersed in a clear isotropic medium of known refractive index. The particles form a mono-particle layer with their tops in a plane. The sample is transported to the field of view of a lens system which displays its magnified image onto the optical sensor of a television system. The immersed sample moves in steps across the field of view of the objective lens. Several images individually

focused at different depths in the particle layer are obtained for each field of view. The operation sequence during viewing involves:

- (a) Movement of some immersed particles into field of view;
- (b) Individual images at several planes of focus taken;
- (c) Movement of more immersed particles into field of view and imaging sequence repeated.

Every particle is viewed in both plane-polarized and cross-polarized light. The samples are stored and are available for recovery and review.

The imaging subsystem consists of:

- (a) A light source capable of narrow-bandwidth output, and a light condenser;
- (b) An objective lens to project a magnified image to a television camera;
- (c) Polarizing filters which will allow particles to be viewed in both plane-polarized and cross-polarized light;
- (d) A television camera capable of recognizing  $10\mu$  particles at any spot over a field of view of  $0.5 \times 0.5$  mm.

The total system weight including television camera is approximately 15 to 18 pounds. This is one of the fixed analysis experiments. Therefore, it is operated in conjunction with the surface sampler, lunar drill, and the sample processor/distributor.

#### 14. Gas Chromatograph

The objective of the gas chromatograph experiment is to provide an analysis of the volatile constituents in lunar surface material. It should detect the following compounds and elements to a specified resolution even when their quantity is as low as  $10^{-10}$  mole of sample gas within the oven structure.

- 
- |                                |                                     |
|--------------------------------|-------------------------------------|
| 1. Hydrogen ( $H_2$ )          | 15. Butyric Acid ( $C_3H_7COOH$ )   |
| 2. Oxygen ( $O_2$ )            | 16. Formaldehyde ( $HCHO$ )         |
| 3. Nitrogen ( $N_2$ )          | 17. Acetaldehyde ( $CH_3CHO$ )      |
| 4. Carbon Monoxide ( $CO$ )    | 18. Propionaldehyde ( $C_2H_5CHO$ ) |
| 5. Water vapor ( $H_2O$ )      | 19. Acetone ( $CH_3COCH_3$ )        |
| 6. Methane ( $CH_4$ )          | 20. Acetonitrile ( $CH_3CN$ )       |
| 7. Ethane ( $C_2H_6$ )         | 21. Benzene ( $C_6H_6$ )            |
| 8. Propane ( $C_3H_8$ )        | 22. Toluene ( $C_6H_5CH_3$ )        |
| 9. Butane ( $C_4H_{10}$ )      | 23. Ammonia ( $NH_3$ )              |
| 10. Methanol ( $CH_3OH$ )      | 24. Acrolein ( $CH_2=CHCHO$ )       |
| 11. Ethanol ( $C_2H_5OH$ )     | 25. Acetylene ( $CH=CH$ )           |
| 12. Propanol ( $C_3H_7OH$ )    | 26. Carbon Dioxide ( $CO_2$ )       |
| 13. Formic Acid ( $HC OOH$ )   | 27. Hydrocyanic Acid ( $HCN$ )      |
| 14. Acetic Acid ( $CH_3COOH$ ) | 28. Hydrogen Sulfide ( $H_2S$ )     |

In operation, a sample of lunar crustal material is collected by the appropriate sampling device on the Surveyor spacecraft and placed in the sample processor/distributor for delivery to the gas chromatograph. The delivered sample is passed through a funnel in the top of the chromatograph into a small oven. The oven is then sealed by a pneumatically operated mechanism and then heated to release gaseous material that may be present in the sample. The gases thus liberated are injected into a helium carrier gas stream in the form of a tight slug. The sample gas is then divided and swept through analytical packed columns. The constituents of the sample gas will have more or less affinity for the packing material in the columns. Through the mechanisms of absorption and/or chemical equilibrium, the passage of each constituent through the columns is impeded for a distinct, reproducible time interval unique for each unknown. This retention time is measured at the effluent end of each column by a signal from a detector which senses the presence of any unknown material other than the helium carrier gas. The outputs from the detectors are fed into

the spacecraft for data processing and transmission back to Earth. From this transmitted data, the identity and approximate quantity of each unknown volatile constituent in the sample can be determined.

This is one of the fixed analysis experiments. Therefore, it is operated in conjunction with the surface sampler, lunar drill, and the sample processor/distributor. As long as the individual particles have dimensions of less than about 5 mm, sample grain size is not important. Oven temperatures can be selected to one of three temperatures: 150, 325, 500°C  $\pm$  10°C. The instrument is capable of cycling through analyses of a large number of selected samples; however, a maximum of thirty minutes should be allowed for each complete cycle. The instrument weighs about 10 pounds.

#### 15. Subsurface Probe

A subsurface probe or logging sonde to carry scientific instruments into a three-foot vertical hole made by the lunar drill at the Surveyor landing site could provide important subsurface information. The sonde would be approximately 1 inch in diameter by 20 inches in length and would weigh about 3 pounds. In operation, the probe is lowered into the 1-1/4-inch diameter drilled hole. If the hole does not collapse, a force of, say, 5 pounds may be required to drive the probe into the hole. If the hole does collapse, however, then the drive mechanism is powered to apply a maximum longitudinal force of 50 pounds to force the device to various depths into the unconsolidated material.

A large variety of in situ scientific experiments could be conceived for a subsurface sonde of this type. For example, experiments to examine the down-hole thermal properties of say conductivity and diffusivity, or the elastic properties as determined by acoustic velocity experiments, or perhaps experiments to examine the electrical or magnetic properties of contacted material are all conceivable. However, it would seem that the most practical and useful experiments would be those providing any information in support of other Surveyor experiments, unique new information, or information about the process and rate of turnover of lunar surface material. The suggested experiments are discussed in the following paragraphs.

a. Density. Density is a valuable physical property of rocks or soil. It would be of most interest if measured on or in lunar bedrock. Knowledge of solid-rock density will assist petrological experiments in determining lunar rock mineralogy and composition. If density is measured in a layer of accumulated debris, it will be possible to estimate porosity if the approximate phase composition of the material can be determined by the X-ray diffractometer. Porosity is valuable in understanding the sorting and packing of the surface debris, hence, some indications of the origin of the layer are provided as well as some engineering data.

This experiment would probably utilize the method of gamma-gamma logging, as employed in the oil industry, in which a directed radiation source (approximately 50 mc of  $\text{Hg}^{203}$ ) is located a known distance from a Geiger-Mueller counter tube. The density is then derived from the knowledge that the radiation received from the source due to scattering is related to the density of the material subjected to the experiment. Accurate measurements require that any background effects be accounted for. Background levels are determined by near complete shielding of the radioisotope source and an observation of the level detected by the same Geiger-Mueller tube.

b. Magnetic Susceptibility. The object of this experiment is to determine the average magnetic susceptibility of a contacted sample of lunar material. The susceptibility measured will most likely be governed by the content of three minerals which have high susceptibilities: free iron, magnetite ( $\text{Fe}_3\text{O}_4$ ), and ilmenite ( $\text{FeTiO}_3$ ). The susceptibility of free iron is so high that a few grains of it in the material will cause a higher bulk susceptibility than 5% magnetite. A susceptibility measurement will, therefore, allow an estimate of the free iron content. Since this phase is most difficult for X-ray diffraction identification, the magnetic experiment is of value--considerably so in approximately determining the oxidation state of surface iron. The origin of the iron from lunar or meteoritic sources can be evaluated on other grounds (Ni%, coexisting phases). A low, but detectable, susceptibility value would suggest that magnetite and/or ilmenite existed in the rocks. A near-zero reading would indicate the absence of these three phases. Knowledge of the iron content could be of use in interpretation of radar data, since iron and iron oxide phases should be highly reflective.

This experiment would probably employ an air core transformer in which the mutual inductance between primary and secondary has been measured for a surrounding medium of permeability approximately equal to one (air or vacuum). Measurements are made by determining the mutual inductance in a known medium and again with the subsurface logging sonde in the drill hole. The difference between the mutual inductance measured under these two conditions is proportional to the magnetic susceptibility.

c. Lunar Heat Flux. The heat flux is a function of the temperature gradient and the thermal conductivity, and for the Earth it has a value of approximately  $1.2 \times 10^{-6}$  Cal/cm<sup>2</sup>-sec. The heat flux from the interior of the Moon will be a function of its past thermal history and the distribution and strength of heat sources; therefore, knowledge of the lunar heat flux bounds hypotheses of bulk composition, differentiation, and physical models of the interior. Specifically, subsurface probes with temperature sensors can be used to measure the temperature gradient and some thermal parameters at drilled sites. Results from these measurements may provide data on regional lunar heat flow, ground-truth for correlating microwave and IR measurements, and location of local thermal anomalies. It should be realized that the validity of lunar heat-flow data will depend on acquiring information from many different sites.

This measurement could be made by determining the thermal conductivity and thermal gradient independently. The best approach to this measurement is probably to use the same technique as used on Earth; that is, to measure the drill-hole temperature over a considerable period of time--say at least a lunation--at two points, one near the top and the other near the bottom of the probe, to determine the steady-state vertical temperature gradient. In addition, it is desirable to determine the thermal conductivity in the drill-hole.

#### 16. Facsimile Camera

The general objective of this camera system is to provide high-resolution stereographic pictures of the Surveyor landing site. The specific objectives are to:

- (a) Provide, as the primary objective, panoramic photographic information of the visible lunar terrain in the immediate vicinity of the spacecraft, up to and including the local horizon;

- (b) Provide measurements of feature size, shape, and range, through photogrammetry;
- (c) Provide photometric, colorimetric, and polarimetric measurements of selected regions of the visible lunar surface, to aid in differentiating the observed features;
- (d) Produce topographic or form-line maps of the observable vicinity of the spacecraft, for use in geologic interpretation of the observed features;
- (e) Monitor the operation of other experiments and direct sample acquisition by the surface sampler;
- (f) Observe lunar surface features at different angles of solar illumination to assist in differentiating and correlating the visual information, in identifying the lunar surface features, and in enhancing the accuracy of the topographic measurements;
- (g) Observe phenomena taking place on the surface of the Moon, such as the formation of new craters by micrometeoroids and secondary solid particles, by successive observations of regions of the lunar terrain and coordination with the results of other payload experiments.

A facsimile camera system was developed as an experiment for the Ranger Capsule scientific payload. The device proved to be extremely rugged, light in weight and reliable, and in subsequent field tests by the Astrogeology Branch of U.S. Geological Survey at the Bonita lava flows, it produced high quality, geometrically stable images that were very well suited to stereographic viewing and reduction techniques. Similar cameras were delivered to the lunar surface in 1966 by the Soviet spacecraft Luna 9 and 13 and produced good images.

The facsimile camera performs the function of transducing visible energy into electrical energy and establishes the format by which picture information is represented electrically. Its major element is a top tube which contains the optical viewing subassembly, plus vertical drive, and scanning mechanisms. These elements provide one degree of motion to the optical system by "nods"

in the vertical plane. The top tube also houses the photoelectric transducers and the first stage of signal amplification. The portions of the high resolution facsimile (HRF) system not in the top tube include an azimuth drive mechanism, which provides the necessary second degree of motion to the optics for rotation in the horizontal plane; motor drive electronics, which provide the power to both the vertical and horizontal drive motors; signal electronics; and synchronization electronics, which provide accurate timing signals to ensure proper playback of the data. The top-tube assembly is housed in a 1.25-inch diameter cylinder approximately 10 inches long. The ports in the outside walls of the top-tube housing are sealed with glass windows which will pass energy in the region of the electromagnetic spectrum from 0.3 to 1.2 microns. Inside the housing and behind each window is a flat distortionless mirror which is pivoted so that it may swing 25 degrees in a vertical plane, thereby generating a 50-degree scan. By this action, each mirror reflects light down the tube onto an image-forming lens, which in turn focuses the light onto the surface of a photosensitive transducer.

The complete device including an extension mast for vertical stereographic pictures would weigh less than 10 pounds.

#### 17. Passive Seismic

This experiment is composed of a three-component, long-period seismometer, a short-period vertical seismometer, a deployment mechanism, and a self-leveling system. The experiment objectives are to provide knowledge of lunar seismicity and information bearing on the Moon's internal structure, physical properties, thermal history, etc. A net of these instruments would have the potential for providing the same detail of information for the Moon that terrestrial seismology has provided for the Earth.

The instrument system for this seismic experiment is similar to the one being developed for the Early Apollo Lunar Surface Experiment Package. The system consists of the following:

- (a) A three-component, long-period seismometer system with a free resonant period of from 10 to 15 seconds, equipped with

displacement transducers (capacitance type) and associated amplifiers to give maximum magnification to one million (sensitivity of 25 millivolts per millimicron of ground displacement amplitude). One component will measure vertical displacement, while two components will measure horizontal displacements that are perpendicular to each other.

- (b) One short-period vertical seismometer with a free resonant period of about one second. The instrument is equipped with a moving-coil transducer and amplifiers to provide an output of 50 millivolts per millimicron of ground displacement at a frequency of one cycle per second.
- (c) Servosystem for leveling the four-component system to within about 10 seconds of arc of lunar vertical. This servosystem will compensate for an initial off-level of plus or minus 5 deg, the latter being accomplished by a built-in mechanical system. The system will also re-level the long-period seismometers during the lunar operating period. The re-leveling will occur automatically and upon command, to compensate for drifts resulting from thermal and mechanical effects, as well as changes in gravity and tilt.
- (d) A deployment mechanism must lower the seismometer package to the lunar surface so that good coupling is provided and that the longitudinal axis is within  $\pm 2$  deg of the local vertical.

If the Moon is found to be seismically active, it would be desirable that this experiment be capable of operating over extended periods of time, say several months, and be operated as part of a lunar seismic net. The total weight of this experiment is about 30 pounds.

#### 18. Lunar Atmosphere Experiment

There are no observations to indicate that the Moon has a substantial atmosphere; however, there are reasons for supposing that a very tenuous lunar atmosphere exists. Dollfus (Ref. 7), based on the polarization of scattered light

from the Moon, established a probable upper limit for this atmosphere of  $10^{-9}$  terrestrial atmospheres, which corresponds to a particle density of approximately  $10^{10}$  particles/cm<sup>3</sup>. Occultation studies based on the electron density have suggested a lower limit of  $10^{-13}$  terrestrial atmospheres which corresponds to a particle density of approximately  $10^5$  particles/cm<sup>3</sup>. If the Moon is presently undergoing degassing then surface pressures up to  $10^{-7}$  atmospheres are possible.

Unless the Moon is a completely inactive body, its atmosphere must include those gases released from the interior as well as those brought to its surface by the solar wind and meteorites. The primordial gases H<sub>2</sub>, He, Ne, Ar, Kr, Xe, N<sub>2</sub>, H<sub>2</sub>O, CH<sub>4</sub>, and NH<sub>3</sub> presumably are being vented continuously but in unknown quantities. The solar wind adds large numbers of H and He atoms. At the same time, it very effectively sweeps away the heavier gases by elastic collisions, charge exchange, and by photoionization and photodissociation. The very light particles, in contrast, are lost principally by conventional acquisition (in a Maxwellian distribution) of velocities greater than the escape velocity.

The nature of the gases present at the lunar surface should offer important clues to the origin of the atmosphere. If there are considerable amounts of CH<sub>4</sub>, NH<sub>3</sub>, and other molecules (or radicals) in contrast to simple atoms and inert gases, then outgassing of the Moon must be an important source. Presumably, the products of nuclear spallation in the surface layers are also being released. However, Ne<sup>20</sup> should be relatively abundant in the solar wind, in contrast to neon formed by nuclear spallation (in which all three isotopes are produced in approximately equal amounts). If the isotopic composition of the gas shows a substantial amount of Ar<sup>36</sup> compared to Ar<sup>38</sup> (that is, if the respective ratio of these isotopes is 5.4, which is typical of primordial gas and of the Earth's atmosphere), and if little Ar<sup>40</sup> is present, then the major source of the atmosphere would have been the solar wind.

In addition to the possibility of estimating the fraction of the lunar atmosphere due to the solar wind and that due to outgassing, the rate at which the latter is proceeding might be estimated from the proportions of Ar<sup>40</sup> (produced continuously by the decay of K<sup>40</sup>) to the primordial fraction and/or the contribution of spallation. Furthermore, the partial pressure of water might be an

important clue as to whether water is stored to any extent as ice or whether it remains at a steady-state level set by the rate of outgassing, before it dissipates rapidly into space.

It seems important that the Moon's atmosphere should be examined before it is thoroughly contaminated by rocket exhaust gases, as the character of the original gases should offer some important clues as to the origin of the atmosphere. It is estimated that the total lunar atmospheric mass is about 100 metric tons and that each Apollo LEM will release up to 5 metric tons of contaminating exhaust gases into this atmosphere (Ref. 8). Therefore, it is strongly recommended that on an early mission the lunar atmosphere be examined for its neutral mass spectrum, neutral particle pressure, total ion concentration, directed ion flux, and ion mass spectrum.

#### 19. Magnetometer

This experiment will measure from a fixed-surface location the magnitude and direction of the lunar magnetic field and its time variations. The specific scientific objectives are: (a) to measure the magnitude, direction and time variation of any lunar magnetic field; (b) to establish the origin of any observed magnetic field, i. e., the extent to which the magnetic field of the Moon is intrinsic and the extent to which it is an accumulated interplanetary field; and (c) to study the interaction between the solar wind and the Moon.

The United States has not made any magnetic measurements in the vicinity of the Moon. However, Russian measurements on Lunik II and Luna 10 have shown that the field near the Moon is approximately 30  $\gamma$ .

This is substantially larger than the interplanetary field (by a factor of approximately 6) but is consistent with theoretical models that predict that the Moon will accumulate a magnetic field from the magnetized solar wind. According to this view, the incoming interplanetary field lines will pile up on the sunlit side of the Moon until their magnetic pressure, combined with the solar gas pressure, equals the stagnation pressure of the solar wind and a standing bow shock will then result. Only a fraction of the solar plasma will then strike the Moon's surface, the rest will slide past the Moon carrying irregular magnetic

fields with it. The stagnation magnetic field will diffuse into the Moon to an extent that depends on its electrical conductivity and on the character of the interplanetary magnetic field.

The question of how much, if any, of the observed field is due to the Moon itself has such important implications that it merits careful study. The discovery of an intrinsic field, even though weak, would indicate that the Moon still has a molten core.

The instrument presently conceived as suitable for this lunar atmosphere analysis is a quadrupole mass spectrometer. The instrument is expected to weigh 12 lb and consume a maximum of 10 watts of power. It records data in a digital mode by mass analyzing (a) ions created in its ion source through electron impact on neutral species, and (b) primary ions trapped in an accelerating field with the ionizing electron source inhibited. The mass analyzer portion of the instrument is entirely nonmagnetic being composed of superimposed ac and dc voltages impressed on a set of four parallel rods. Mass scanning of the spectrometer is accomplished by slaving the analyzer voltages to the address register of a multi-channel scaler (MCS). Ion pulses arriving at an electron multiplier detector are amplified and stored in the appropriate MCS channels according to their mass. The data in the MCS is then telemetered. A data rate of approximately 250 bps is desirable.

It would probably be desirable to add a Redhead or Trigger gage to this experimental package for direct measurement of the lunar atmospheric pressure. Both instruments have been flown before. It would weigh about 5 lb and use 1 watt of power. The data output is analog and could be kept very low. It would be desirable to do this experiment simultaneously from the surface and from a lunar orbiter. The experiment should have a lifetime of at least one lunation to look for dawn meridian and orbit effects.

Alternatively, the interplanetary fields that pile up on the subsolar side of the Moon will have to be replenished at a rate that depends on bulk electrical conductivity of the Moon. Estimates of the latter, derived from magnetic measurements, would also have implications concerning the Moon's internal composition and structure.

In addition, this field replenishment, since it governs the extent to which the solar wind can reach the surface, will strongly influence: (1) the rate at which the Moon can accumulate various constituents from the solar wind; (2) the effect on the surface of a continuous or nearly-continuous bombardment by the energetic solar wind protons; (3) the amount of neutral hydrogen and other gases re-emitted by the surface to form a tenuous lunar atmosphere; and (4) the influx of energetic electrons (accelerated at the bow shock) and the subsequent generation of X-radiation when they strike the surface.

The instrument could be either a flux gate or low field helium magnetometer. The latter is preferable, because it is not as sensitive to temperature effects. It should be composed of three orthogonal sensors each capable of measuring magnetic field strength along its axis to a sensitivity of 1 gamma in an ambient field strength of between 1 and 150 gamma. The instrument should also be capable of measuring field strength fluctuations from the steady-state condition up to 10 cps.

The magnetometer sensor should be placed some distance from the spacecraft or experiment package, say at least 25 feet, to reduce magnetic effects from the spacecraft or other scientific instruments. A cable tether and spring launch mechanism would be ideal for getting the sensor away from the spacecraft. In this mode of operation the instrument would be directly exposed to the extremes of temperature prevalent in a lunar cycle.

The instrument including sensors, electronics, launch mechanism, and balsa-wood protective sphere would weigh about 10 pounds.

## 20. Solar-Plasma Spectrometer

The purpose of the plasma probe is to make measurements of the low-energy charged-particle environment of the lunar surface and to aid, thereby, in the interpretation of the magnetometer data by a study of the interaction of the Moon and the interplanetary plasma and their magnetic fields. The instrument will be capable of measuring the interplanetary charged-particle energy spectrum as a function of arrival direction, energy, angular distance from the subsolar point, and time. Solar plasma measurements on the lunar surface are interesting from at least four points of view.

- (a) The nature of the interaction of solar plasma with the Moon is an intriguing problem in basic plasma physics. This interaction is different from that with the geomagnetic field and cannot be predicted theoretically with any certainty. It is not even clear at present whether or how often the plasma strikes the surface directly.
- (b) Information about the Moon itself may be obtained, relating to its electrical conductivity, its possibility of retaining an atmosphere, and the possible effect of solar corpuscular radiation on the lunar surface layer by the mechanism of sputtering or electrical charging.
- (c) The structure and propagation velocity of "solar streams" and "solar shells" (in the terminology proposed by Chapman) can be studied by measuring the time intervals between the observations of sudden changes in plasma properties at the Moon and at the Earth. These intervals are expected to be as much as a few minutes in length, depending upon the relative positions of Sun, Moon, and Earth.
- (d) The measurements may permit inferences as to the length, breadth, and structure of the magnetospheric tail of the Earth.

The instrument to accomplish the above measurements should have the following characteristics:

- (a) It should have the widest possible angular aperture. Since the direction of the incident solar wind changes by 180 deg during a lunar day, and since we have no a priori information on the magnetic field in which the instrument will be placed, the instrument should have fairly uniform sensitivity to particles arriving from anywhere in the upward hemisphere.
- (b) It should distinguish clearly between undisturbed solar wind plasma and plasma that has traversed the collisionless shock (assuming that it exists) ahead of the Moon. Space probe data

on the Earth's shock demonstrate that this differentiation can be made on the basis of the energy spectrum of the particles and their angular distribution.

- (c) It should measure the principal plasma properties (bulk velocity, density, and temperature) for both the ion and the electron components with reasonable precision and resolution.
- (d) It should be capable of registering changes in the plasma properties within a few seconds so that time correlations with plasma probes on Earth satellites can be made accurately.

The suggested instrument for this experiment would include several "Faraday-cup" plasma probes, pointing in different directions so as to provide reasonably uniform coverage of the entire upward hemisphere. Each sensor would contain a current collector and several highly transparent grids, to one of which (the modulator grid) a square-wave ac potential is applied, alternating between  $V+v$  and  $V-v$ . Since charged particles of the appropriate polarity having energy-per-unit charge (in volts) between these two values are alternately repelled and transmitted, the dc potential  $V$  determines the mean energy measured and the ac potential  $v$  is the half-width of the "energy window." A complete energy spectrum is obtained by successively changing  $V$  and  $v$  over the range of interest.

When the flux is not isotropic, analysis of the relative amounts of current to the several probes will determine the mean direction of plasma flow and a measure of the anisotropy.

## 21. AC Electric and Magnetic Fields

The measurement of simultaneous electric and magnetic field fluctuations near the lunar surface is also of scientific value. Field and particle measurements at the surface may actually be made inside the plasma sheath associated with the near presence of such a large-scale, electrically conducting boundary. In addition to the new information that may be obtained, knowledge of the time-varying electric and magnetic fields may be necessary to resolve any ambiguities, even of a temporal character, that may arise in the plasma and dc magnetic-field

data. A satisfactory interpretation of these data may require more of an understanding of the physics of the interaction between the shocked solar wind and the lunar surface than can be obtained without knowledge of the more rapid time-varying electric and magnetic fields.

The kind of instrumentation that has been used, or is planned, for measurements near Earth on satellites and in interplanetary space should be adequate for use in lunar exploration. The ac magnetometer could utilize a search coil sensor (especially appropriate at frequencies below  $\approx 1000$  cps) or some sort of relatively large, air-core loop that could be erected or unfurled. The electric field sensor could consist of a cylindrical antenna or of some configuration of spheres or cages at the ends of a nonconducting rod. Sensors of the above kinds can all be built at a weight of from one to a few pounds. The electronics employed are generally quite similar whether E or B field measurements are made. They consist of amplifiers and filters, very often in the form of a spectrum analyzer, that will measure the spectra of the rapid fluctuations at a low enough telemetry data rate to be practical. The weight and power for such electronics are typically less than 5 pounds and 2 or 3 watts.

## 22. Ranging Experiment

The objective of this experiment is to determine the selenographic location of a lunar landing site by measuring the range between one or more soft-landed vehicles on the Moon and a station on Earth. A random range resolution of at most 5 meters, and preferably 1 meter, is desirable. Range measurements to several Surveyor landing sites, that are so distributed that they will provide a selenodetic control network, are desirable. From these ranging data, the lunar landing site location will be readily tied into any selenodetic control network by reducing measurements taken from orbiter photographs that contain images of the Surveyor landing site and reference lunar landmarks. These data, in addition to having a direct application to selenodesy, lunar mapping, and future missions, are expected to be of great value in the solution of problems posed by celestial mechanics and geodesy.

Several such Surveyor sites on the Moon should define the physical libration constants precisely enough to allow the prediction of the physical libration

of the Moon to one arc-second selenocentrically and should also provide information on the lunar moment-of-inertia ratios to an accuracy of about 1 part per 1000, thus leading to an improved lunar physical ephemeris. Such an improved physical ephemeris can be used to precisely define selenodetic control networks. Finally, these data will provide a precise check on the variable terms in the parallax of lunar theory. In the past such checks have been made only from angular information, as no technique was available for determining range. Now it has been shown that the required precision can be achieved using the Deep Space Network with S-band doppler and ranging. As the selenodetic experiments on Lunar Orbiters and Surveyors continue and the lunar ephemeris and computations are refined, it may be practical to use the technique also to determine lunar distortions and librations.

Two independent techniques could be used to provide these ranging data. First, radio doppler and ranging techniques as presently demonstrated for Surveyor and Lunar Orbiter have precision of about 5 meters. Second, a laser ranging instrument would also be used. This technique has a precision of at least 5 meters and potentially 1 meter.

Basically, the equipment for the radio doppler is a part of the Surveyor bus. The equipment for the laser instrument would consist of a transmitter at an appropriate terrestrial observatory and a reflector at the lunar landing site. Total instrumentation on the landed spacecraft, including the reflector-antenna, a pointing mechanism, and the mounting, would weigh about 10 pounds.

### 23. Dosimeter

In support of the manned program, it would be desirable to fly an experiment to provide data on the biological hazards from energetic radiations resulting from extended surface missions. A variety of methods are available for instrumenting this experiment, but the instrument used should (a) be "tissue equivalent," that is, it should provide a direct measure of the energy that would be absorbed in human tissue and (b) have a dynamic dose-rate range extending from cosmic ray background up to the dose rate from a large solar proton event (perhaps several hundred rad/hr).

A "tissue equivalent" ionization chamber would be a simple instrument for this experiment. It could be fabricated to weigh only about one pound and to consume only a few milliwatts of power.

## SECTION IV

### LUNAR ROVING VEHICLE

#### A. GENERAL

One of the most obvious and perhaps more important roles of the roving vehicle in the lunar mission will be geological reconnaissance, or rather, the ability to extend the local measurements of Surveyor or Apollo into the surrounding area. The best scientific payload to accomplish this task would be the Surveyor List II (Table 2) experiments with the addition of a photo-imaging device to provide the eyes for navigating and guiding over the lunar surface. This payload, however, is more science in terms of weight, power, and volume than a 175 pound SLRV can accommodate. A useful scientific payload intended for this weight-class vehicle is nevertheless achievable. It is comprised of a photo-imaging device, a geosampling device, and a combination X-ray diffractometer-spectrometer (Table 5) with a total weight of about 35 pounds. This is an excellent payload for geological reconnaissance, for it will accomplish almost the same measurements as a geologist would during a traverse. The imaging device will observe the general lay-of-the-land, its structure, stratification, and topographic form; the X-ray diffractometer will identify mineral species. It should be realized that a chemical basis alone is incapable of classifying the many diverse products of rock-forming processes; thus, chemical elemental analysis experiments will not distinguish crystalline rock from volcanic glass or ash with the same chemical composition, nor a physical mixture of local debris from a crystalline rock. The accepted schemes of rock classification are based on texture (the size, shape, and geometrical relation of grains in a rock) and the identification of the minerals in the rock. From these parameters, information regarding the nature, geologic history, and origin of the rock may be defined.

In the event this much payload weight cannot be allowed, a suggested alternate payload would consist of the photo-imaging device, a geosampling device, and a version of the Surveyor X-ray diffractometer.

If the payload weight of the roving vehicle should drop below 25 pounds, then it will probably be necessary to lower the scientific objectives of the mission

Table 5. Typical SLRV Science for Geological Reconnaissance

Instrument/Experiment	Weight in Lbs.	Objectives
1. Photo-Imaging	8	Provide real-time images for guidance. Provide stable images for making topographic maps and examining the surface form, structure, stratification and texture. Examine acquired sample material.
2. Geosampler/Transporter	5	Acquire samples from a fixed point under the SLRV and distribute to the combination X-ray diffractometer and spectrometer instrument.
3. Combination X-Ray Diffractometer and Spectrometer	20	Provide mineralogical and elemental analysis of lunar surface material acquired at a number of fixed points on a roving vehicle traverse.

by foregoing definitive mineralogical analysis. A suggested alternate payload to accomplish elemental chemical analysis would consist of the photo-imaging device and a combination X-ray alpha-scattering instrument. The total weight of the alternate payload would be about 22 pounds. A minimum useful payload could be formed from the photo-imaging device and a nondispersive X-ray technique with a total weight of only 15 pounds. These SLRV instruments are discussed in the following subsection.

## B. SLRV SCIENCE

### 1. Photo-Imaging

The objectives of the photo-imaging instrument are as follows:

- (a) Provide real-time images that can be used to guide the roving vehicle;
- (b) Acquire dimensionally stable images from which topographic maps can be made by photogrammetric methods;
- (c) Provide reconnaissance-eye, type-geological information;
- (d) Provide near-field information on surface structure and texture, with the capability to detect particle sizes down to at least 1 mm.

A variety of sensors and camera systems could perhaps be adapted to the roving vehicle mission; however, the selected system should meet the following requirements which are felt to be essential to the objectives of the roving vehicle mission.

- (a) A stereographic baseline of the camera system of preferably 3 feet but no less than one foot. The baseline may be vertical or horizontal.
- (b) At each position of the roving vehicle from which an image is obtained, a measurement should be transmitted that gives the orientation with respect to the local vertical within 0.5 degree.
- (c) The resolution of the imaging system should be at least 6 minutes of arc at 20-percent sine wave response or better.

- (d) The imaging system should be able to scan in elevation at least 40 deg above and 60 deg below the horizontal axis of the SLRV.
- (e) The system should provide images with at least a 36-decibel peak-to-peak signal-to-rms noise ratio, for scene highlight luminences ranging from 25 foot lamberts to 2500 foot lamberts; also, it is desirable that the system have a 24-decibel peak-to-peak signal-to-rms noise ratio for operating in lunar shadows where the scene highlight luminences may range down to a few foot-lamberts.
- (f) The system should provide for 360 deg panoramic coverage or coverage of a select sector.
- (g) The imaging system should be able to distinguish at least 13 grey levels.
- (h) The total system weight including spacecraft attachments will be about 8 pounds.

## 2. Geosampler/Transporter

This instrument consists of a small, very lightweight sampling device, suitable for lunar surface and near-subsurface sampling conditions, and a simple transporter arrangement for presenting sample material to an array of fixed analysis scientific instruments. Thus, the geosampler/transporter will perform two basic functions:

- (a) Sample acquisition from a fixed point under the roving vehicle
- (b) Sample distribution from the sample device to an analysis point.

A study of the soil properties of the lunar surface as portrayed by the Surveyor and the Luna landing dynamics and experiments suggests a granular surface with a bearing strength of perhaps 5 psi that can be perforated without a great deal of energy and hard drilling. Nevertheless, it is desirable, from a sampling point of view, to be able to pierce and acquire some samples from consolidated material.

A number of lightweight devices would be applicable for this purpose, especially if hard-rock piercement is not required. For example, a so-called rigid helical conveyor, with drill tip, could satisfy the requirements. The instrument would weigh less than 5 pounds including deployment mechanism and sample chute and tray. It would be capable of sampling the "typical" lunar soil to a depth of perhaps 5 inches. It size-sorts particles so as to diminish the content of those over 500 $\mu$  and largely reject those over 1000 $\mu$ ; below 500 $\mu$  it does very little sorting. The instrument has drilling capability in weakly consolidated material and pumice-like rock.

### 3. Combination X-Ray Diffractometer and Spectrometer

The X-ray diffractometer will be used to conduct mineralogical analyses of lunar surface material acquired at a number of fixed points on a roving vehicle traverse. The primary objective of this instrument is to identify the types and relative abundance of the various crystalline phases expected to be present in a lunar sample. The instrument will provide diffraction data of sufficient quality to identify any of the major rock-forming and accessory minerals.

The X-ray spectrometer will be used to conduct an elemental analysis of lunar surface material acquired at a number of fixed points on a roving vehicle traverse. This mode of analysis can detect elements from sodium through uranium; however, only those elements from sodium through nickel are expected to be present in sufficient quantity to allow detection. In general, the instrument should be capable of detecting elements with the following limits of sensitivity (by weight):

<u>Element</u>	<u>Limits of Sensitivity</u> <u>%</u>
Sodium	0.5
Magnesium	0.2
Aluminum	0.1
Silicon	0.1
Sulfur	0.1
Chlorine	0.1

Potassium	0.05
Calcium	0.05
Titanium	0.05
Chromium	0.02
Manganese	0.02
Iron	0.02
Nickel	0.02

The combination of these two instruments represents a powerful tool for understanding lunar geology. It should be used in conjunction with the imaging system, which should be capable of detecting the textural properties of lunar material to a resolution of at least 1 mm.

This combination experiment will weigh about 20 pounds and will receive its samples from the previous experiment (geosampler/transporter). The complete experiment can be packaged into about 0.6 cubic foot, and in operating mode, it will require about 5 watts of power. It should be physically located on the roving vehicle near the geosampler/transporter. Also, lunar surface sample material should be viewed by the imaging system either before or after analysis.

#### 4. Combination X-Ray Spectrometer and Alpha-Scattering

The scientific objective of this experiment is to provide an in situ chemical analysis of the lunar surface at a number of fixed points on a roving vehicle traverse. The experiment will provide qualitative and quantitative information on elements present as major constituents ( $> 0.1\%$ ) in lunar surface materials.

The useful range of response for the X-ray mode extends from sodium through uranium. Only certain elements from sodium through nickel are expected to be present as major constituents. Since the energy of the characteristic X-radiation decreases with atomic number, the sensitivity of the method becomes poorer for the lighter elements. Experimental data indicates the following sensitivities for accuracies of  $\pm 10 - 20\%$ ; down to  $Z = 24$ , better than  $1\%$ ; to  $Z = 16$ ,  $1 - 2\%$ ; to  $Z = 13$ ,  $2 - 5\%$ .

In the X-ray analysis, as a result of the inherent resolution limitation of the detector, it is exceedingly difficult to resolve adjacent atomic-numbered elements, such as Mg and Al. The use of one to three selected absorption filters or optically dispersing channels may be required to overcome this problem.

The alpha-scattering mode of the experiment is capable of analyzing all elements between boron and calcium (except Ne and Ar) with a sensitivity of at least 3 atomic percent. The sensitivity for carbon is better than 1 percent. The elements between titanium and zinc can be identified only to within an atomic number of about  $\pm 1$ , those between zinc and silver to within an atomic number of  $\pm 3$ , etc.

For both modes of the experiment, a method of sample excitation is needed. A radioactive alpha source that would be common to both modes of analysis is  $^{242}\text{Cm}$  ( $T_{\alpha} = 6.11 \text{ MeV}$ ). A source with an intensity of 100 - 200 millicuries will be suitable.

For the alpha-scattering mode, the detectors will consist of silicon semiconductors, probably of the diffused-junction type. Solid-state detectors are used because of their high energy resolution and efficiency for charged-particle spectroscopy.

The requirements of the X-ray mode also call for a pulse-amplitude energy-dependent detector. A gas-filled proportional counter(s) is currently the most suitable device for this purpose. By varying the filling gas, pressure to fill, effective path length, and mass absorption in the window, a proportional counter can be made to respond preferentially over portions of the energy range. Within the next 2 years, the state-of-the-art of solid-state detectors may advance sufficiently for them to replace the proportional counter in this application.

The experiment will weigh 14 pounds including a deployment mechanism, and power requirements during an operating mode are less than 2.5 watts. The complete experiment can be packaged into about 0.5 cubic feet. If an RTG power supply system is used on the roving vehicle, this instrument will require shielding.

In operation, the instrument excitation source and sensor must be deployed to within a few inches of the lunar surface and then retracted before the roving vehicle resumes its traverse.

## 5. X-Ray Spectroscopy

The scientific objective of this experiment is to provide an in situ chemical analysis of the lunar surface at a number of fixed points on a roving vehicle traverse.

The suggested instrument for this experiment will utilize nondispersive X-ray emission spectroscopy and a radioactive source for excitation. Nondispersive X-ray spectroscopy does not require dispersing crystals and defining slits for optical discrimination, but rather relies upon electronic techniques. Sensitivity and accuracy are considerably degraded by abandoning crystal dispersion; however, the instrument becomes much simpler and lighter in weight, especially when a radioactive excitation source is used.

The instrument is made up of an excitation source, a counter for detection, a signal amplifier, power supply, and deployment mechanism. Detection of the low-energy X-rays from the radiated sample of lunar material will be accomplished by a gas-filled proportional counter. By varying the filling gas, pressure of fill, effective path length, and mass absorption in the window, this type of detector can be made to respond selectively over specified portions of the emission energy range. The output from the detector goes to a signal amplifier and then to a pulse height analyzer for energy discrimination.

The total weight of this instrument including a deployment mechanism will be about 8 pounds. In operation, the instrument excitation source and sensor must be deployed to within a few inches of the lunar surface and then retracted before the roving vehicle resumes its traverse. If an RTG power supply is used on the roving vehicle, this instrument will require shielding. Power requirements are about 4 watts.

### C. OTHER MISSIONS FOR SLRV

The Apollo sample return experiment is recognized as one of the most important in the entire lunar program, affording as it does the opportunity for elaborate Earth-based investigation of the isotopic composition, chemistry, mineralogy, and physical state of the lunar surface material. To extend this experiment beyond the Apollo landing locations appears highly desirable. Therefore, a possible mission for a small rover is the collection of samples along an extended (up to hundreds of km) traverse, followed by the delivery of the samples to a collection point where they would be returned to Earth, presumably by an Apollo spacecraft. The traverse could be either from one Apollo landing point to another or from a Surveyor to an Apollo site.

The minimum instrumentation for this type of mission would include the SLRV imaging device plus techniques for acquiring lunar samples. This latter task suggests that two separate sampling modes may be required — one for hard rock material, and another for sifting the particulate material that appears to form much of the lunar surface.

In addition to the geological reconnaissance and sample collection missions, the SLRV can be instrumented to accomplish a number of other tasks within the framework of a lunar exploration program. For example, later Apollo missions landings in potentially hazardous regions may call for advance certification of sites. A properly instrumented SLRV could provide site certification data extending over a much greater area than is possible with fixed-point vehicles such as Surveyor, with higher resolution viewing than can be reasonably accomplished by orbiters, and with the main advantage of many tactile measurements over the entire area of the landing site.

Three scientific instruments will be required on an SLRV to perform the site-certification mission: a photo-imaging device to permit guidance of the vehicle over the lunar surface and to provide topographic data useful for Apollo, an automatic penetrometer or other device for bearing strength measurements, and an inclinometer to discern low angle slopes.

Apollo site certification requirements are in part derived from the configuration and size of the LM landing vehicle. Thus, the LM landing pads are placed about 5 meters away from the central vehicle axis. The clearance between the bed of the LM and the plane of the pads is about 60 cm. If the bed of the vehicle were to strike the surface, it could cause a disaster.

The LM weighs about 10,000 pounds. It falls free under lunar gravity from 10 feet above the surface and lands at a nominal velocity of 10 ft/sec on 4 pads, each about 1 meter in diameter. The landing gear shock absorbers limit the maximum dynamic pressure to 12 psi. The static pressure is 0.33 psi (assuming the weight is equally distributed).

From the foregoing discussion, several effects can be deduced that will be important to LM, and therefore these effects must be amenable to seeing and analysis. These effects are:

- (a) Protuberances. The imaging device must be capable of seeing the limiting case that can cause puncture or bottoming of LM. Although LM can actually clear a 60 cm protuberance, the limiting case given in the OMSF (Office of Manned Space Flight) Requirements calls for identification of 50-cm protuberances.
- (b) Slopes. The imaging device must be capable of seeing a slope of 12 deg extending over an area larger than the dimensions of LM. Although LM can actually land on a 15-deg slope, the limiting case given in the OMSF Requirements calls for identification of 12-deg slopes.
- (c) Slope-Protuberances. The imaging device must be capable of seeing the low-angle short baseline features that would produce protuberances resulting in bottoming of LM. A right circular cone with base equal to 10 meters and conical surface sloping at approximately 6 deg would produce a 50-cm protuberance. Thus, the imaging device must be capable of recognizing a 6-deg slope displayed over an area with a radius of 5 meters.

- (d) Soil Bearing Strength. The sensitivity of the soil mechanics instrument should be greatest over the quantitative surface property range which is critical to a LM landing.

The total SLRV science payload to accomplish site certification measurements would be approximately 15 pounds. This, of course, includes the TV or other device for guidance.

Other SLRV missions could include instrument emplacement or geophysical reconnaissance. Possible experiments for this latter type of mission would include a gravity profile, a magnetic survey, or perhaps an active seismic survey. This type of mission will probably have its greatest meaning later in the lunar program, however, after much data and analysis has more clearly delineated our multiple working hypotheses.

#### D. INTEGRATED OR KING-SIZE ROVER

Up to this point the Surveyor bus has been considered in the role of a rather conventional delivery vehicle. That is, conventional in the sense that most of the subsystems required for payload support both in transit and on the lunar surface were common to all types of missions, and no allowances were made for spacecraft design to integrate some of these functions into the off-loaded payload. For example, a Surveyor-Rover combination has two separate communication systems, two separate electrical power systems, etc. By integrating all of these redundant functions into the Rover, thus making Surveyor only a carrier, or considering an Apollo-transported Rover, it is likely that the roving vehicle science payload can be greatly increased (See Table 6) to include the basic Rover photo-imaging device, most of the Surveyor List II instruments, other desirable experiments, and a more efficient sample-acquisition technique.

The Surveyor List II (Table 2) instruments to be included here for the Rover mission of geological reconnaissance are as follows: (1) sample processor/transporter, (2) X-ray spectrometer, (4) petrographic microscope, and (5) gas chromatograph.

A gamma-ray spectrometer would be a practical instrument to add to the scientific payload for a mission of geological reconnaissance on these larger

Table 6. Integrated Rover Science for Geological Reconnaissance

Instrument/Experiment	Weight in Lbs.	Objectives
1. Photo-Imaging	8	Provide images for guidance and displaying the surface topographic form, structure, stratification and texture. Provide high resolution images of acquired sample material.
2. Hard-Rock Drill & Particulate Sampler	17	Acquire samples.
3. Sample Processor/Transporter	5	Prepare sample from drill for the fixed-analysis instruments.
4. X-ray Diffractometer	15	Identify the types and relative abundance of crystalline phases present in lunar samples.
5. X-ray Spectrometer	15	Provide information on the elemental composition of lunar material.
6. Petrographic Microscope	15	Identify lunar rock types and determine their genesis — detection and composition of glass — examination of particulate material as to texture, etc.
7. Gas Chromatograph	10	Identify some of the volatile constituents in lunar surface material.
8. Gamma-ray Spectrometer	14	Identify characteristic gamma-ray lines for radiogenic isotopes of potassium, uranium, thorium.

roving vehicles. A moderate-sized gamma-ray spectrometer on a roving vehicle will be able to determine the degree of geochemical differentiation of the traverse to an effective depth of some 10-20 centimeters. Observed variations can be correlated with photographic and other geophysical observations as well as with broad survey radioactivity measurements from orbiting spacecraft. A gamma-ray spectrometer will indicate promising locations for drilling and sample acquisition based on measured variations in the near surface composition, despite any appearance of homogeneity at the surface. Used in conjunction with an X-ray spectrometer, the two systems will provide a separate surface and subsurface analysis.

The gamma-ray detector will be a scintillation crystal of sodium iodide coupled to a photomultiplier tube. A shell of plastic scintillator will surround the inorganic crystal for the purpose of eliminating an unwanted response to the charged particle flux. After suitable shaping and amplification, the analog output signal from the photomultiplier is digitized and stored in a memory. The contents of this memory will be read out periodically and transmitted back to the spacecraft for relay to Earth. Much of the electronics can be time-shared with a nondispersive X-ray spectrometer, if the mission profile permits. Allowing for a 3 x 3-inch crystal of NaI, the total weight of the instrument will be 12 to 14 lb and 6 to 7 lb if nondispersive spectroscopy is included on a time-sharing basis. Power requirements will be about 4 watts for a complete instrument and 1 to 2 watts for the detector and its associated electronics. The gamma-ray detector should be deployed away from the main mass of the roving vehicle at a height of 0.5 to 2 feet above surface. The vehicle must be clean of interfering sources of radioactivity. An RTG power supply will make the experiment impossible.

It is also desirable that a hard-rock drill technique be used for sample acquisition on this mission. This is because of the probability that the Rover will find hard-ground outcrops, flows, or perhaps large pieces of consolidated ejecta, and it would be very desirable to analyze the mineralogy and petrology of this type of material.

Under development is a small, low-powered rotary impact sampling drill which will produce the fragmented rock powder required by the analytical instruments from rock as hard as dense basalt. Since the drill is not an efficient

sampling device in highly vesicular rock and some under dense particulates, attempts will be made to incorporate into this drill a particulate acquisition device. Should this not prove feasible, two samplers, a drill, and a particulate sampler may be proposed for the Integrated Rover. In hard rock the drill would require about 20 minutes to produce samples for all the instruments, use about 100 watts peak power, have a depth capability of about a foot, and weigh approximately 10 pounds. The particulate sampler would acquire and transport samples in less than five minutes, draw about 25 watts of power, and weigh approximately 7 pounds.

## SECTION V

### ROUGH-LANDED PROBES

#### A. GENERAL

Rugged instruments could be carried in a hard lander probe completely enclosed in a shock absorbing material, such as balsa wood, delivered to the lunar surface in mode similar to that planned for the Ranger Block II missions, and later studied as a part of the Lunar Survey Probe concept. Impact forces on the order of a few hundred Earth "g" could be experienced by the probe in this mode of delivery; thus, most of the probe weight would provide the necessary shock-absorbing material to protect the scientific instruments. Another mode of delivery is to use a Surveyor-type spacecraft to give an almost soft-landed probe. However, it is important to realize that, regardless of the selected mode of delivery, the most useful mission of the rough-landed probes will probably be one of geological reconnaissance of the rougher hard-to-land areas of the Moon.

The landed probe will require some method of erecting and stabilizing; also, the instrument sensors will require access to the lunar environment.

#### B. SCIENTIFIC INSTRUMENTS

The scientific instruments that are best suited for the rough-landed probe mission of geological reconnaissance (See Table 7) are discussed in the following paragraphs.

##### 1. Facsimile Camera

This instrument would provide high-resolution pictures of the landing site, and it is desirable that it have panoramic, stereographic, and colorimetric capability. The parallax needed for stereo effect is best produced by raising or lowering the top-tube assembly to give a vertical stereo. This appears to be the simplest and most rugged design and will give satisfactory results. (See Surveyor Instrument 16 in Table 2.)

Table 7. Rough-Landed Probe Science

Instrument/Experiment	Weight in Lbs.	Objectives
1. Facsimile Camera	10	Provide high resolution stereo panoramic pictures of the landing site.
2. Hard-Rock Drill & Particulate Sampler	17	Acquire samples.
3. Sample Process/Transporter	5	Prepare samples from drill for the fixed-analysis instruments.
4. X-ray Diffractometer	15	Identify the types and relative abundance of crystalline phases present in lunar samples.
5. X-ray Spectrometer	15	Provide information on the elemental composition of lunar material.
6. Petrographic Microscope	15	Identify lunar rock types and determination of their genesis; detect and determine composition of glass; examine particulate material texture, etc.
7. Gas Chromatograph	10	Identify some of the volatile constituents in lunar surface material.

## 2. Hard-Rock Drill

It is desirable to have a hard-rock drill technique for sample acquisition on this mission. The drill discussed for the Integrated Rover would be satisfactory; however, it may be necessary to restrict the drilling depth to only a few inches because of packaging requirements. (See Instrument 2 in Table 6.)

## 3. Sample Processor/Transporter

This instrument would receive samples of lunar material from the hard-rock drill and it would have the function of both preparing and distributing this sample material to the fixed-analysis instruments. (See Surveyor Instrument 10 in Table 2.)

## 4. X-ray Diffractometer

This is one of the fixed-analysis instruments; its specific objective is to identify the types and relative abundance of crystalline phases present in the samples of lunar material. (See Surveyor Instrument 11 in Table 2.)

## 5. X-ray Spectrometer

This is one of the fixed-analysis instruments; its specific objective is to provide information on the elemental composition of samples of lunar material. (See Surveyor Instrument 12 in Table 2.)

## 6. Petrographic Microscope

This is one of the fixed-analysis instruments; its objectives are the identification of lunar rock types and minerals, detection of glass and estimate of its composition, determination of the textural properties of rocks and particulate surface material, and identification of minerals present in only small amounts. (See Surveyor Instrument 13 in Table 2.)

## 7. Gas Chromatograph

This is one of the fixed-analysis instruments; its objective is to provide an analysis of the volatile constituents in the sample material. (See Surveyor Instrument 14 in Table 2.)

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It has not been shown that all of these instruments could be packaged to survive rough-area landings, but they are the instruments most likely to be useable in this mode, and they would provide important information on the otherwise inaccessible regions of the Moon.

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